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THE MONIST

THE ELECTRONIC THEORY OF MATTER.[1]

> "Wie Alles sich zum Ganzen webt!
> Eins in dem Andern wirkt und lebt."
> —*Goethe.*

THE subject of the considerations that follow is proposed as the sixth under the division of physics in the published program of this congress. Unquestionably the proposal was most timely and fortunate, for no theme of purely scientific content is more important or more central on the stage of interest or more worthy of the attention of the assembled savants of two continents. Surely it is eminently appropriate that the New World should foster the New Knowledge, should master it, acclaim it, proclaim it, and advance it.

The most obvious criticism upon any attempt to treat this theme on the present occasion would seem to be that the barrel is too large for the hoop. So far and wide reaching is the new doctrine of matter, so interpenetrative of so many remote and alien disciplines, that any half-way adequate presentation of even the most near-lying considerations would necessarily pass swiftly beyond the largest bounds to be assigned this paper and easily expand into a stately volume.

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[1] This paper, read (in Spanish) at the First Pan-American Scientific Congress (Santiago de Chile, Dec. 25, 1908 to January 5, 1909), has appeared thus far only in the *Trabajos del Cuarto Congreso Cientifico* (*1° Pan-Americano*), Vol. V, pp. 1-22, Santiago de Chile, 1910.

We must begin then with renunciation. The attempt can not be made to detail but only to suggest some of the proofs (which are manifold and decisive) of the actual existence of the corpuscle, sub-atom, or electron, as the uniform elementary constituent of the visible universe is variously named. The isolated independent subsistence of this corpuscle is the central revelation of the new knowledge. It was first discovered many years ago, and proclaimed to the world as the fourth or radiant state of matter by Sir William Crookes, after whom the vacuum tubes in which the green phosphorescence accompanying the passage of an electric current were and still are named. That something called cathode rays emerged from the cathode or negative pole and moved in right lines, was proved by the shadow cast by an interposed mica cross. The English declared these rays were particles, shot out from the cathode (pole) against the inside walls of the tube; but the Germans held it was only ether waves stirred up at the pole and propagated rectilinearly. That the English were right was shown conclusively by subjecting the rays first to magnetic and then to electric attraction, whereby it appeared that they behave in all ways precisely as minute particles laden with negative electricity. Amazing is the control which the experimenter exhibits over these flying hosts of electric atoms; by deft manipulation of his infinitely fine magnetic or electric fingers he may turn the stream of corpuscles as he will and even bend it into a spiral or into a circular hoop far more supplely than one might bend the superfinest Damascus blade. But inconceivably more delicate still is the touch of the mathematical reason, whereby even the individual electron is caught in its flight and forced to tell the secret of its speed. For one may subject the flying particles simultaneously to opposite electric and magnetic influences by immersing them in two coexistent and mutually annulling fields of force, so that they fly undisturbed straight from the negative to the positive pole. These two self-destroying forces are Hev and eX, whence $v = X/H$, whereby v the velocity of the corpuscle is known when we know H the magnetic and X the electric force, both of which are readily measured. This velocity increases with the exhaustion of the tube from eight thousand up to one hundred thousand kilometers per second, which is many thousand times the mean speed even of hydrogen molecules at the highest temperature ever yet attained.

But far more wonderful and incomparably more important than this determination of a variable velocity is the determination of a constant, the most fundamental yet discovered in nature. Science itself may be defined as the eternal search for invariants amid the eternal flux of variants, and this astounding constant of which I am about to speak reminds us indeed of Plato's unwavering axis of the universe turning forever in the lap of Necessity. In the equation $Hev = Xe$, the symbol e denotes the negative electric charge borne by the individual corpuscle. If we take away the magnetic force, leaving only the electric, this latter will bend the path of the flying corpuscle as gravity bends the path of the level-aimed cannon ball into a parabola. Now Galilei has taught us the formula for the amount (s) of the bend or the fall in the time t; it is $s = \frac{1}{2}\alpha t^2$ where α is the acceleration in question. Here the acceleration is the force Xe divided by the mass m of the corpuscle; the time is the tube length l divided by the velocity v; and the distance s is the descent of the green spot at the end of the tube;

hence $s = \frac{1}{2}X(e/m) . (l^2/v^2)$, whence $e/m = (2v^2s/l^2X)$, where all on the right side is known. Hereby is determined this ratio of the electric charge to the mass of the flying corpuscle, and this ratio is found to be everywhere the same (unless indeed the velocity of the corpuscle, of which it is in strictness a function, approaches that of light).

The value of this remarkable constant (for all ordinary velocities) is in the accepted C. G. S. system no less than 17,000,000 (1.7×10^7). Why is it so large? Is it because the charge e is so great, or because the mass m is so small? This question can be answered and has been answered by the exquisitely beautiful experiments of the two Wilsons (C. T. R. and H. A.) on the formation of clouds by condensation of vapor around nuclei. Not only does the water collect around particles of dust but also around any particles charged with electricity: nay more, it refuses to collect except around nuclei until the vapor reaches eightfold saturation. Now it has been found possible to free a cylinder of air from dust, and supersaturate it with vapor, and then to form in it suddenly a dense cloud by electrifying its particles with radiations from radium or still better by charging its individual molecules with electrons shot out from a metal plate played on by ultra-violet light. By attracting electrically these drops coagulated around these molecules one may suspend them in the air of the cylinder like balloons or make them fall as slowly as one will, so that their velocity of fall may be measured; and Stokes has deduced the formula for this velocity, $v = 2/9 . ga^2/\mu$ where g is the known acceleration of gravity and μ the known coefficient of viscosity; hence a, the radius, and thence the size of the drop is found; and hence by measuring the amount of watery vapor deposited one finds the number of the drops and so can count the number of electrified molecules, that is the number of corpuscles, since each molecule has but one negative electron. Plainly, if by one chance in a trillion two corpuscles should light on one molecule, their mutual repulsion would dislodge them instantly.

By electrometric methods one may find the total charge of electricity on the total water, the sum of the drops, and dividing this by the number of drops or corpuscles one finds the charge *e* on each, and then on dividing this by the constant ratio there results the mass *m* of each corpuscle. These numbers turn out to be appalling in their minuteness. The charge *e* equals $310/10^{12}$ of an electrostatic unit, or one one-hundred-trillionth (10^{-20}) of an electromagnetic unit, and is the long well-known approximate value of the charge borne by an atom of hydrogen in the electrolysis of dilute solutions. The mass *m* of the corpuscle proves to be six hundred quintillionths of a gramme (6×10^{-28}), a degree of parvitude far beyond the utmost stretch of the imagination. The same may indeed be said of the atom of hydrogen, but the mass of this atom is 1700 times[2] the mass of the corpuscle. Hitherto this hydrogen atom has been conceived as standing on the remotest confines of matter, but the new knowledge shows us a still lower world of corpuscles, nearly 2000 times smaller.

At this point it may be proper to enter a caution. It is almost universal to speak of this corpuscle as of invariable mass bearing an invariable charge of negative electricity, and the calculations and experiments do indeed yield results uniform within the limits of error. But we must remember that these experiments and calculations have always treated and apparently must always treat not the individual corpuscle but millions on millions of corpuscles and atoms. The results then were only averages of countless numbers of individuals, and the constancy of such an average implies nothing at all as to the constancy or inconstancy of the individual, just as the comparative steadiness of the rates of birth, death, marriage, homicide and the like, even in a population of a few millions, implies nothing whatever as to the rate in any particular family. For all we know the range of individuality among atoms and corpuscles may be quite as great as among suns or planets or men, and this we must say even in face of the famous dictum of Maxwell, that atoms of any one substance have all the marks of manufactured articles, being all exactly alike.

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[2] Later determinations raise this number to 1830 or even 1872. M. Perrin's experiments on "visible molecules" indicate that the mass of a hydrogen atom is 1.63 quadrillionths ($1.63/10^{24}$) of a gram. Hence the mass of an electron would be $0.8/10^{27}$ gram.

Returning from this digression we must now ask what is the mass and what is the charge of electricity of the corpuscle? It is precisely here that the new knowledge calls for the profoundest transformation of our conceptions, for it derives the phenomenon of mass in the corpuscle solely from the motion of the flying charge of negative electricity. We all know that work is needed to start a body in motion, as a car even on a perfectly smooth track. For any particular body having a particular velocity v, the amount of work necessary is perfectly definite, namely, $\frac{1}{2}v^2$ multiplied by a constant, M, called the *mass* of the body. We say the kinetic energy imparted is $\frac{1}{2}Mv^2$. This supposes the motion is in a vacuum, which is never the case; in practice the motion is always in some fluid, as water or air. Then we all know that more work is needed, according to velocity. One fans oneself gently with ease, but violently only with great effort. In fact, the fluid is also set in motion as well as the body, and this calls for energy or work. How much fluid is dragged or pressed along with the body will depend on the body's size, shape and speed and on the density of the fluid. Some of the simplest cases have been studied. Sir George Gabriel Stokes has found that in case of a sphere the work done on the fluid is $\frac{1}{2}M'V^2$, where M′ is the mass of a volume of the fluid half as large as the sphere (shown by Green, 1833), so that the total energy imparted is $\frac{1}{2}(M + M')V^2$. Now all motions take place in the all-pervading ether. It follows then that, if the ether itself has mass, when put into movement it must absorb energy or require work, and hence that some perhaps infinitesimal part of the mass of a moving body even in a vacuum must be due to the swirl set up in the ether. In the case of the moving corpuscle the analogy is not absolutely perfect, but exact enough to make intelligible the statement that if a conducting sphere of radius r, having a charge e and mass m, be set moving with velocity v, the energy developed in the ethereal magnetic field has been proved to be $\frac{1}{3}k(e/r).v^2$, so that the total work done is $\frac{1}{2}[m + \frac{2}{3}k(e/r)]v^2$, and the ordinary mass m is thus increased by $\frac{2}{3}k(e^2/r)$, which stands for the inertia overcome in the ether. (This k is a factor due to the crowding together of the lines of force into a plane through the sphere center, and perpendicular to the motion, and increases rapidly as the velocity becomes great.) Since e is extremely small, this increase is wholly imperceptible in case of all single bodies subject to our senses or experiment. But for the corpuscle, when r becomes inconceivably small, this so-called electric mass assumes important proportions, yea, it accounts for absolutely all the mass of the corpuscle, which must have this electric mass and need have no other at all. For Kaufmann has measured the value of e/m (or m/e) for the various corpuscles emitted with various velocities by radium; and J. J. Thomson has calculated k for these velocities. It turns out that the calculated relative increase (due to rising velocity) in the electrical mass is constantly equal to the observed relative increase in the whole mass, whence one must conclude that the electrical mass is the whole mass, for if there were any ordinary non-electrical mass, however small, it would certainly not thus increase apparently with the increasing velocity. The mass of the corpuscle is thus not located, at least in any appreciable degree, in the corpuscle itself, but only in the universal ether around it.

Imagine a sphere surface perfectly rigid but absolutely void, empty even of ether itself, a mere round hole in universal ether. If set in motion this hollow sphere would gather mass as it gathered velocity, but the mass would not be inside, it would be wholly outside, inwrought in the universal eddy set up in the infinite ether. In this sense the mass of the moving hollow sphere would be coextensive with the whole space filled by ether, and in this sense we may say the same of the mass of a flying corpuscle: it reaches throughout the world. We may imagine it as a mere needle-point from which Faraday tubes of force radiate to the utmost stars. But since the ether bound by the tubes varies as the squared density of the tubes, and hence varies inversely as the fourth power of the distance from the sphere center, it follows that the corpuscle mass is after all highly concentrated round the corpuscle core. For an easy reckoning shows that the corpuscle radius r is only about five millionths of the molecule radius, which is commonly taken as the hundred millionth of a centimeter; that is, of course, in *order of magnitude.* Hence from the surface of a molecule to the surface of a corpuscle at its center the mass intensity would increase more than a trillionfold.

It follows that one can no longer affirm with perfect rigor the principle of the conservation of mass, for the masses vary constantly with the velocities of the corpuscles. But to our gross senses even when armed with the most delicate instruments these variations might forever remain imperceptible. However, Heydweiler claims to have actually detected a difference in the joint weights of water and copper sulphate before solution and after, and Wallace holds that the mass of water is changed by freezing—highly interesting results that await confirmation. But it must not be supposed that the notion of mass itself is hereby eliminated or even reduced to greater simplicity. For all these results assume to start with the assumption that the ether itself has mass. Calling then to one's help the Faraday image of tubes of force and still more the hydrodynamics of vortex rings, one may deduce from ether-mass the mass of all material bodies; but mass itself adheres along with time and space inexpugnably in our reasonings.

Corpuscles therefore are; atoms also are; how then shall we think them related? As the corpuscle mass is only 1/1700 of the hydrogen atom mass, shall we think this smallest atom as compounded of 1700 corpuscles? There are many reasons against such a doctrine, reasons that lead one to think the number of corpuscles in the atom as always small. But shall we think the atom as in any case composed of corpuscles? There seems to be no escape from such a conception, which lies directly across the path of thought. For many experiments that cannot be mentioned here show that corpuscles are all-pervasive. Metals heated pour them forth, as do all other substances hot, and some shoot them out even when cold, as rubidium, and at fearful speed, as all radio-active substances; yea, if we had instruments fine enough we might detect them in every substance, and everywhere maintaining the constant ratio e/m inviolate. Moreover, that the corpuscle is closely related to the atom is clearly seen in the fact already mentioned that the corpuscle's and the hydrogen-atom's charges of electricity are the same.

Before trying to construct imaginatively the atom out of corpuscles we must recall that there are rays (as Goldstein's *Canalstrahlen*) of positive as well as of negative electricity, that are deflected by a magnet oppositely to the negative cathode rays. For them the ratio e/m is not constant and never exceeds 10,000, which is also its value for hydrogen ions in electrolysis of dilute solutions. It is natural to figure thus the positive corpuscle as a sphere of positive electrification, about the size of an atom. Of course such a sphere implies an equal and balancing amount of negative electricity, and this we imagine distributed throughout the sphere as equal corpuscles or units of negative electricity. Since the atom is permanent, this distribution of negative electrons in the positive sphere must form a system in stable equilibrium, and the question arises, what arrangement of the electrons would constitute such a stable system? The problem is mathematico-mechanical, and its general solution lies beyond the range of our present powers of analysis; but if we propose the problem not for space but for the plane, we may solve it and get a system of answers quantitatively different but formally analogous to those that must be rendered for threefold space.

At this point theory and experiment have joined hands in a most friendly fashion. As early as 1881 the present Cavendish professor of physics at Cambridge, stimulated by the brilliant experiments of Crookes, in a long neglected but now classical paper in the *Philosophical Transactions,* discussed the motion of a charged sphere in an electric field, thereby laying the foundations of the doctrine of electric mass. Twenty-three years later (1904) he advanced to the discussion of the equilibrium of a system of negative electric charges abandoned to their mutual attractions in a positively electrified shell.* He showed that the configuration of planar equilibrium is (in general) a regular polygon concentric with the sphere, but for six particles the equilibrium is unstable, one particle will break ranks and rush to the center, while the other five form a regular pentagon. Similarly if there be seven, eight or nine; if there be ten, three will form an inner equilateral triangle, and so on up to seventeen, when one of the inner ring will again break ranks and fly to the center, leaving an inner ring of five, and an outer ring of eleven. (Four corpuscles cannot be in planar equilibrium at rest, but only when the four are in rapid rotation. At rest they are at the corners of a regular tetrahedron whose edge equals the radius of the sphere. Six corpuscles are balanced at six corners of a regular octahedron.) When the number reaches thirty-two, the three-ring system becomes unstable, again a particle seeks the center, leaving an inner ring of five, a middle ring of eleven, an outer ring of fifteen. Looking at it another way one may ask how many must be put inside a ring of n to make it stable. The answers are: for 5, 0; for 6, 7, 8, each 1; for 9, 2; for 12, 8; for 13, 10; for 15, 15; for 20, 39; for 30, 101; for 40, 232. You see how rapidly (as the cube of n) the inside corpuscles multiply as the outer ring increases in number. The structure must be compact, densely peopled toward the center, not hollow like a shell.

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* For an additional note see page 480.

The whole scheme of numbers has been worked out by J. J. Thomson (*Philosophical Magazine,* 1904) mathematically, and a beautiful experiment first made for another purpose by the American Mayer, afterwards under other forms by Wood and Monckmann, confirms his results. On a water surface any number of small equally magnetized needles are made to float by being thrust through cork discs, only like poles being above the water. These repel each other like the negative electric corpuscles. The sphere of positive electrification is represented by a magnet hung above the water, the opposite pole pointing downward. This holds the magnets in groups in stable equilibrium, and the arrangements of the magnets actually observed agree excellently with the arrangement required and predicted by mathematical analysis. Provisionally then, we may proceed on the working hypothesis that the atom is a system of corpuscles composed of a number of concentric sub-systems all held in stable equilibrium by an enclosing sphere of positive electrification. This conception may be somewhat vague and may hereafter require modification, but it is far clearer and more precise than was possible a few years ago and constitutes a notable advance in physical theory. We have spoken of the configuration as stable, but this stability must not be understood too strictly nor as always equally rigid. Since we may have an outer ring of five, six, seven or eight with only one at the center, it is plain that if there were seven in equilibrium, neither an increase nor a decrease of just one would disturb the system much; but if there were sixteen the arrangement would be one of two rings, eleven in the outer, five in the inner; take away one and the arrangement persists with only ten outside; but add one and the two-ring system is no longer stable, a particle goes to the center, the rings remain unchanged, a three-ring system is formed. A better though more complex example is afforded by the group of eleven, ranging from 58 to 68 corpuscles (Thomson); all these have five rings, thus, in order:

19	20	20	20	20	20	20	20	20	20	21
16	16	16	16	17	17	17	17	17	17	17
13	13	13	13	13	13	13	14	14	15	15
8	8	8	9	9	10	10	10	10	10	10
2	2	3	3	3	3	4	4	5	5	5
58	59	60	61	62	63	64	65	66	67	68

Here we see that if a corpuscle be injected into the 58-system it produces the least possible disturbance, place is made for it in the outmost ring and the others remain as they were, a 59-system results. But if a corpuscle be added to this it can find no place in any ring but the central; it must find its own way to the center ring or else dislodge a corpuscle from the outer ring, which corpuscle will then dislodge another from the next and so on till a corpuscle is finally dislodged into the innermost ring from the one next to it. Still another corpuscle may be injected and another and another, profoundly altering the original arrangement but preserving the outer ring unbroken.

So it goes on, the center becoming denser and the outer ring more stable till the total number 67 is reached, having the arrangement 20, 17, 15, 10, 5. Here the central mass, though it may still make room for another corpuscle, is very steady and stubborn, so that now when another corpuscle is injected, the outer ring yields, absorbs it and now has 21. Accordingly this 67-system is like that of 58, most stable, changing least from its original form. The group of arrangements from 59 to 67 corpuscles forms a series all having twenty in the outer row, the stability of each system increasing up to the last, after which a new group begins with similar properties but only eight members. Now these corpuscles are units of negative electricity. As the number of these inside the atom increases, the outer ring remaining the same, the stability, measured by Q, the work necessary to disperse all the units infinitely apart, increases; the more inside the more firmly the outside ring is held. Hence the 59-system will be least stable, a unit would easily fly off leaving only the preceding 58-system. If we suppose this 59-system neutral, on losing this negative unit it becomes comparatively at least electro-positive; in fact the most strongly electro-positive of this series of arrangements. The following members must lose more and more negative units in order to become electro-positive as this 59-system. The 67-system is charged with the utmost negative excess and so is most electro-negative or least electro-positive. The outer ring of 20 will in fact admit no more negative units inside, but on still further addition a new outer ring of 21 is formed and a new series begins with a highly electro-positive system of 68 and again runs down to an electro-negative system of 77, in each of which the outer ring is 21. Herewith then we attain a new notion of valency. For the 59-system has only just sufficient corpuscles inside to maintain its outer ring of 20; the fifty-ninth in the system, the twentieth in the ring, might easily break away leaving only 19 outside and the atom positive from the loss of the negative unit. But it could not remain positive for it would draw to it another corpuscle and so restore its ring of twenty, and this process might be repeated. But as many as 8 negative corpuscles might be injected into the ring of 20, raising the total number to 67; hence we may say this 59-system corresponds to an atom of valency 8 for a negative unit charge and of valency 0 for a positive charge, since it could not assume permanently the positive unit charge. Consider next the 67-system. It is impossible to drive a single negative unit within the 20-ring; if one collide with the atom it stops in the outer ring making 21, but this ring is very unstable and would easily lose this electric unit; hence we may say this system has no negative valency or a negative valency equal to 0. However, this same 67-system might lose one, two or three. . . .or even eight atoms, reducing its negative, i. e., raising its positive, charge, though with harder and harder work; it could not lose more without changing its outer ring and passing into another series. Hence we may say that its positive valency is 8, just as its negative valency is 0. It is needless to dilate upon the intermediate members. Similar considerations show that we may arrange them thus:

No. of corpuscles . .	59	60	61	62	63	64	65	66	67	68
Valency .	+0	+1	+2	+3	+4	—3	—2	—1	—0	
	—8	—7	—6	—5	—4	+5	+6	+7	+8	
	Electro-positive					Electro-negative				

Such series are actually found among known chemical elements. Such are helium, lithium, barium, boron, carbon, nitrogen, oxygen, fluorin, neon, and neon, sodium, magnesium, aluminum, silicon, phosphorus, sulphur, chlorin, argon. Of course it is not meant for a moment that any such planar arrangement is actually present in chemical atoms; their corpuscles must be arranged in tridimensional space; but it can hardly be doubted that relations analogous to the foregoing, only more complicated, must characterize spatial as well as planar arrangements. If we call the tendency of a system to shed a corpuscle *corpuscular pressure* (*outward*), then it appears that this pressure changes abruptly at the end of each series; thus at 58 the pressure is very low, at 59 very high; at 67 low; at 68 high: it falls through the electro-positives down to and through the electro-negatives. We might then define positive valency of an electro-positive (or negative) as the greatest number of corpuscules it can lose without abrupt fall in corpuscular pressure; the negative valency of the electro-negative is the number it can gain without sudden rise of corpuscular pressure. Upon these definitions and conceptions has been erected a most plausible theory of chemical combination, into which we cannot enter. But one other aspect may not be passed by in silence. While no one affirms that the planar forms of equilibrium are the actual forms assumed by corpuscles in atoms, it seems hardly possible that they are not similar thereto, similar enough to allow a most important conclusion. These forms are arranged in series, and the members of these series bear striking resemblances. There are rings outside of rings, and rings outside of these, and so on. Thus around a central one there is a ring of 6, giving 7; and around this a ring of 11, yielding 18; and around this a ring of 15 making 33; and around this a ring of 18, making 51 in all; and around this a ring of 21, which makes 72; and around this still another of 24, or a total of 96.

It seems impossible that atoms consisting of these or any such systems of corpuscles should not have many likenesses in property. We are reminded of a determinant of a definite form, whose degree is raised by bordering it successively by parallel lines above and below, on the right and left. The general properties of the determinants remain the same. If then all possible forms of equilibrium should actually be realized as chemical elements, of necessity these elements would fall into series and in fact a twofold series which might be expressed by a vertical and horizontal alignment, the elements in the vertical rows being alike in their central rings but differing in the number of rings; those in a horizontal row being alike in the number of rings and in their outer ring but different in their inner rings. Herewith then we are lifted up to what is commonly regarded as the apex of chemical theory, the periodic law of Mendelyeev, which thus appears not as an empirical observation, however great or important, but as an inexorable necessity of the mechanical laws of configuration and equilibrium. It is most remarkable also that herewith the law is explained not only in its rigor where it is rigorous, but also in its laxity where it is lax. For there is no necessity that all the possible forms of equilibrium should be actualized; there might very well be gaps, even considerable gaps, in both the vertical and horizontal series. In that case some gap, say in a vertical row, might have next to it some actual form in a near-lying parallel line, which would thus present not an exact but only an approximate repetition of property.

Thus the electronic theory of matter yields not only a vivid idea of the necessary existence of a double system of valences among atoms, and of the probabilities and nature of chemical combinations, but also yields deductively in a highly acceptable form the confessedly highest and most significant induction yet reached in chemical theory. This conception of the atom not as an infinitesimal grain, strong in solid singleness, as Lucretius fancied it, nor yet as a vortex-filament in an incompressible frictionless ether, so sleek and slippery as to wriggle out from under the edge of the keenest knife and sharpest scissors, as Helmholtz and Kelvin conceived it, but as a highly organized community with members held together in unity in stable equilibrium, not at rest but in a system of complicated movements of inconceivable velocity, whose very swiftness itself contributes indispensably to the stability of the configuration (see p. 480),—this conception not only imparts new grandeur to physics but aligns it on the one hand with astronomy, on the other with biology and even anthropology. For we are all familiar in general terms with the planetary system and also with Bode's law, a special case, it would seem, of some principle of balancing, such as reaches from the atom to the constellation, from the star dust of a nebula to the most complex organization of human society. Indeed the principle of natural selection would seem to be hardly less operative in the world of brute matter than in the world of life.

More specifically, however, the electronic theory casts a broad beam of light on some long outstanding enigmas of astronomy. The motion of comets, presenting in the vast sweep of their tails an apparent repulsion from the sun, finds in this theory a long desiderated explanation. At this point science has to thank a large number of widely separated conceptions and personalities. It was the British Maxwell who as early as 1873 confirmed the suspicion of the German Euler (1746), that ethereal undulations must produce a longitudinal pressure along the ray of heat, and three years later the Italian Bartoli reached a similar, more general conclusion by a wholly different path. The mathematical prophecy declared this pressure to be $E(1 + r)/v$, where E is the energy and v the velocity of light, and r the coefficient of reflection of the receiving medium. But this phenomenon is so extremely subtile as long to have eluded the keenest observation, though the unerring finger of mathematics was pointed at it steadily for twenty-eight years.

At length (1901) the Russian Lebedev succeeded in detecting and even in measuring it. Two years later the Americans Nichols and Hull not only repeated Lebedev's experiment with far higher precision, but showed decisively that the observed value of the repulsion agreed within the limits of error with that foretold by the English clairvoyant Maxwell. Of course this repulsive push is inconceivably minute, and on even a very small sphere it would be imperceptible in comparison with the extremely feeble attraction of gravity. However, the latter decreases as the mass or as the cubed radius, while the repulsion decreases as the surface or as the squared radius, of a spherical particle. No matter then how much greater the attraction than the repulsion on any given sphere, as the radius decreases the repulsion must finally gain the upper hand, the particle sufficiently minute must be repelled by the light away from the sun. A particle of earth 0.00001 of an inch in diameter would hang balanced between the push and the pull; if larger it would fall, if smaller it would rise and fly away before the thrust of the light. Now we need not indeed have recourse to electric corpuscles to find particles much below this critical magnitude, and the phenomenon of cometary tails blown backward from the sun with inconceivable velocity, as by the breath of a god, is readily intelligible as resulting from the now demonstrated pressure of light.

Into the details of this matter it is impossible to enter here; suffice it that the illustrious Swedish physicist, Svante Arrhenius, has subjected the whole subject to rigorous calculation which has been in the main verified, at certain points amended, by Schwarzschild, so that the enigma of cometary motion may now be regarded as solved. It is found in fact that the maximum direct pressure at the surface of the sun is 2¾ mg. per square centimeter. While gravitation sets an upper limit to the diameter of the repelled particle (0.0015 mm.) the diffraction of light sets a lower, namely, about 0.1 the wave length of the light in question. Only particles whose diameters lie between these limits can be repelled, all others are attracted. The greatest theoretic repulsion is 19 times the attraction of gravitation on a particle of water; but the heterogeneity of solar light reduces this by nearly half, leaving as maximum only the tenfold of gravitation on a water sphere of 0.00016 mm. diameter. Since molecules fall far below this size, it appears that Maxwell's law does not apply to gases. But here again the corpuscle vindicates its great importance in cosmogonic theory. For the gases near the sun must be at least partially ionized, since its light is rich in ultraviolet rays and these provoke the radiation of ions. But these ionized gases, as proved by the Wilsons, are readily beclouded by the vapor condensing around the ions or corpuscles. The drops thus formed must be repelled by the light pressure, or if too heavy must fall toward the sun and bear away with them the negative electricity, leaving the gas positively laden. Hence the great part played by electricity in cometary phenomena.

While the second and third of Bredichin's groups of comets are easily understood as composed of hydrocarbon particles, the first group shows repulsion nineteen times as great as gravity, and the comets of Rooerdam and Swift (1893 II and 1892 I) even 37 and 40.5 times as great. Such repulsion would require a specific gravity only one-tenth that of water, but it may well be that hydrocarbon spherelets subjected to expulsion of hydrogen under intense solar heat may be turned into sponge-like carbon pellets of the levity required.

The combined conceptions of the forward thrust of light and the universal radiation of corpuscles give us a widely imaginative vision of the heavens above us. The corona of the sun with its greenish pearly light is no longer a mystery. We think of it as composed of particles near the critical sizes and hence held suspended in the sky, like the coffin of Mohammed, between the pull of gravitation and the push of the light, two forces obeying the same law of inverse squares. Its tenuity transcends all conceiving, it being five million times thinner than the head of the comet, and its whole mass if of coal would be burned upon earth in a week. Nevertheless it is something, and it assures us that an endless drizzle of still finer dust is steadily poured out by the sun into surrounding space. In perhaps six thousand billion years the sun might dissipate itself entirely. Unless time be finite it would follow that at this rate all the suns in the universe would have dissolved unending ages ago and vanished like the baseless fabric of a dream. Meantime, however, there has been integration proceeding *pari passu* with disintegration. Since the earth in flight round the sun sweeps up about twenty thousand tons of meteoritic matter yearly, it is easy to reckon that the sun must catch some three hundred milliard tons in the storm that drives forever about him. These meteorites are in fact the building stones of the suns. Of what are they themselves built? According to Nordenskjöld, they are woven together of metallic atom on atom, the universal floating dust of dissolved or dissolving worlds. An awful, a tremendous cycle!

As the sun thus inspires and expires matter like some stupendous lung, similarly it respires electricity. The cloud particles repelled by light-pressure bear away negative electric nuclei and leave a positive charge behind of nearly 250 milliard coulombs, enough to dissolve 24 tons of water. As the solar dust aggregates into meteorites it dispels its negative electrons and these are drawn in a ceaseless flood toward the sun by its positive charge. The sun is thus at once a source and a sink of electrons streaming into and from it, to and from the uttermost walls of the world.

We look aloft into the azure heavens and think to behold a sky unflecked by the minutest cloud. But reason perceives even there an eternal whirlwind of cosmic dust swirling around planets and stars and darkling suns. Well for humanity that the veil of this absorbent mist is flung abroad over the whole heavens! Else would the dome of the sky glow like a furnace, and the countenance of creation be withered and blasted. But not only do these nebulas and frozen stars shield the earth from planetary death; they are the very guardians of the universe itself (according to Arrhenius) against that heat-death (*Wärmetod*) with whose frightful specter Clausius has so long appalled the stoutest hearts of science and philosophy. For in his second law of thermodynamics the German declared that the entropy of the universe tends to a maximum while the energy remains constant. Now this entropy (of a body) is its total heat divided by its absolute temperature. It measures the amount of heat turned into a body in the process of exchange and so rendered unavailable for outward effect. The one universally observed case is that bodies at unequal temperatures tend to exchange heat till they attain the same temperature, when all effective interaction ceases. Applying this observation to the universe, Clausius declared that it was tending to such equilibrium, which would suspend all effective activity, and this universal uniform condition he named heat-death, and taught that it was inevitable, merely a matter of time — a fearful piece of reasoning, which it seemed equally impossible to accept or to refute. But the facts were against Clausius, for least of all men would he deny the past was infinite, hence the universe had had time to run down infinitely often, nevertheless it is manifestly not run down but running on still. Since it has not met the *Wärmetod* in the infinite past, neither need it do so in the infinite future. Maxwell imagined an intelligent demon sorting out the atoms in a uniformly heated gas, by opening the windows of an invisible partition for the passage of each fast-moving particle and shutting them against the slow-moving one, thus sifting them into two apartments, the one hot and therefore able to work on, the other cold. We know, however, of no such demons, though it would be rash to deny them all existence. But on the other hand molecules moving swift enough (more than 11 kms. per second) must tear themselves away from the earth's attraction, leaving behind their slower fellows, thus sorting out the two classes after the fashion of Maxwell's demons. In this way perhaps the moon has gradually lost her atmosphere. So too may the nebulas lose fast-flying molecules that wander into their outer parts and retain only the slower ones and so remain or even become cool. Meantime the fast flyers would be caught in the widespread atmosphere of some condensing star and so raise still higher its rising temperature. Whether or no this be the exact fashion in which the universal activity is maintained, we may be sure that it is maintained in some fashion, and the dreadful presage of universal heat-death that has so long oppressed the scientific consciousness may now be dismissed as the nightmare of a fevered dream.

Still other riddles of the heavens have yielded to the divination of the corpuscular theory. Since we must now think of the sun as sprinkling all space with an incessant shower of dust, clearly the earth too must be thus sprinkled. The atmosphere can no longer be thought as imperceptible beyond 100 kms., but must certainly reach an average height of 400 kms. Were it not for the electric charges with which the particles are laden, the amount of sun-dust that could reach the earth could hardly exceed two hundred tons yearly, one one-hundredth only of what actually reaches us in meteors and shooting stars. On the contrary, Nordenskjöld reckons the cosmic dust positively charged that reaches the earth at ten million tons yearly, and Chamberlain advocates a planitesimal theory that considers the planets as mainly built up of collected meteors. Be that as it may, the significance of the negatively laden particles in the higher regions of our atmosphere is beyond question. Of the luminous effects of wide-scattered dust in the air, the appalling eruptions of Krakatoa (1883) and Mount Pelée (1902), which reddened the sky for months, have furnished examples. On a far grander and more benignant scale the sun powders the upper air into unearthly radiance. Inhabitants of the polar regions have the nightly vision of the Aurora Borealis in two forms long confounded but now clearly distinguished: the one a nearly steady phosphorescent gleam swelling in arch on arch toward the apex of the sky; the other consisting of beams, of fountains of light spouting their torrents of splendor zenithward from the fluttering draperies of flame that fringe the northern horizon. The explanations of these two classes are of course not quite the same, and in their detail one must distinguish between the maximal and minimal years of sunspots; but in general one may say that the negatively laden particles shot out in perpetual tempest from the sun must beat upon the atmospheric envelop of the earth, which is speeding on as through a driving rain. It is the equatorial regions that are full exposed to this tempest. Great however as is the velocity of the particles, they do not in general pierce through this envelop, but are caught as it were in the net of the lines of the earth's magnetic force. Round these they spin in descending converging spirals toward the poles. On impinging upon strata of air as dense as in a vacuum tube they act as in such tubes and exhaust their energy in the fitful gleams peculiar to cathode rays. In case however of a maximal year of sunspots the velocity of the projected particles is enormously increased and they drive on nearly in straight lines in spite of the suction of the lines of force both in the sun's and even in the earth's magnetic field. Hence the Aurora may in these years descend even toward tropical regions. It is at once perceived that the relation between the two phenomena of sunspots and polar light must be intimate and so it is, but into this there is no time to enter.

Still another astronomical puzzle, not however of polar but of tropical observation, seems now in fair way toward solution. The inhabitants of even higher latitudes may behold morning and evening at the equinoxes a cone of light rising from the horizon and called zodiacal from its connection with the zodiac. It is certainly a luminous cloud of particles glittering in the sunlight. Some have thought it to be the last remnant of nebular dust still circling the sun like a ring. But according to Arrhenius both the zodiacal light itself and its still more perplexing *Gegenschein* are due to the same corpuscular storm that pours steadily out from the sun and down upon it from all surrounding space. Surely enough has now been said to show that the corpuscular theory has the widest-reaching astronomic and cosmogonic bearings.

May it not also have biologic significance? The problem of the origin of species on our planet has gone through a variety of phases. Linnæus held that the Infinite Ens had in the beginning created just so many species, which remained unchanged down to our own day. This rigid conception was shaken by Lamarck and others a century ago, but again restored to acceptance by the great authority of Cuvier. Finally it went down forever before the researches of Darwin and the school of evolution. More recently De Vries has detected species in the very act of transvolution, not however through the gradual accumulation of infinitesimal variations, but by finite leaps or mutations establishing a new species in a single generation. Meantime the deeper problem of the origin of life on our planet has not been advanced toward solution, unless the successive recognition of one proposed solution after another as unsatisfactory may be said to be advancing. Thinkers of the highest rank still cling to the notion of "spontaneous generation," under the compulsion of such reasoning as this: there was a time, no matter how remote, when there was no life on the earth; now there is life; therefore sometime between now and then life began to be. Others however spy out another possibility, namely, that life was imported from some other planet. The illustrious Kelvin insisted that the maxim *omne vivum e vivo* was as sure as the law of gravitation and hence was driven to maintain (1871) the hypothesis that life had been borne to our planet on some meteorite, some disrupted fragment of another world. But the difficulties that embarrass the development of such a notion seem quite unconquerable. More acceptable is the modern idea of panspermia, hinted by Richter as early as 1865. In a word, this doctrine holds that the germs of life are scattered as spores throughout all the deepest abysses of space, that they are driven by light-pressure along the sunbeams from planet to planet, from system to system, on journeys that may last for thousands or ten thousands of years. The intense cold of the interstellar spaces need not chill them to death since they are unaffected by a bath of liquid hydrogen (—252° C.). They need not dry out, they need not suffer any destructive chemical change, as oxidation, on their solitary flight from world to world, since evaporation and chemical processes are suspended in that Lethean flood. They need not be too large for the fingers of the light to push before it, since they have been discovered having diameters between 0.0002 and 0.0003 mm., and are doubtless often much smaller, magnitudes well within the grasp of the sunbeam. But how could they be lifted up into the higher regions of the planetary atmosphere, and there surrendered to the propulsion of the waves of ether? Currents of air might lift them a hundred kilometers from the earth, but could never release them from the atmospheric envelope. Here again one must invoke the omnipotence of the electron. The negative-laden sundust that kindles the Aurora fires in the upper air must also beat upon these spores and charge them with electricity. So charged they must powerfully repel each other in every direction and some would be launched outward into the depths of ether and there seized and sped onward by the impulsion of the light. Is the electric field strong enough for this action? Assuredly. An electric field of two hundred volts per meter would suffice. Such are familiar near the earth's surface, and far intenser ones must prevail in the regions of polar light.

Undoubtedly it is a most perilous voyage upon which such a germ of life sets out from the system say of α Centauri to that of our own sun. The immense majority of these ether-farers would almost certainly be lost and perish; but here and there some one would arrive after nine thousand years safe at the utmost borders of our solar world and there by chance light upon some grain of sundust in the reflection of the zodiacal light and be borne along therewith sunward within the planetary ring and even into the atmosphere of some planet, as our own, which would seize upon it with gravitation and slowly drag it to the earth. Perilous too would be the landing on the shores of Time, yet some lucky sailor would succeed and so would establish a form of life upon this planet. Surely a most tremendous conception, striking wonder and awe through the hardest heart! Amazing too it is to reflect that this prodigious idea, so carefully wrought out and bulwarked at every point by the adamantine pillars of mathematical calculation, should have been anticipated in its grandest proportions by the brooding fancy of the pre-Christian Gnostics! For in the Naassene scriptures preserved to us by the good bishop Hippolytus in his *Refutatio omnium haeresium* we find creation described allegorically in the parable of the Sower as the sowing down of seeds from the unportrayable Godhead. Moreover in the deep-thoughted Gnostic Basilides we find repeatedly the same idea, and the new knowledge has actually adopted his favorite technical term "Panspermia" as its own, to express this most recent of astronomico-biological ideas. Life then, at least in its germs, is everywhere pulsing and throbbing throughout the universe and when the finger of time points to the accepted moment the myriad forms of life leap into being out from the teeming womb of ether. We may also see that these forms are probably nearly the same, at least closely allied even at opposite poles of the Milky Way, and man may feel his blood kinship with the tenants of the remotest world. It is impossible then to repress the suggestion that the actual forms of life, being everywhere what they are, have in themselves some deep-lying hitherto unsuspected reason for being thus and not otherwise, some reason profound as the properties of numbers or the logical necessities of the geometry of Euclid.

May one not even venture to hint that the biological import of the corpuscular theory is not yet exhausted? That in the almost endless divisibility of the atoms into sub-atoms or electrons there inheres some undiscovered connection with the pangenesis required in theories of heredity? That the mysteries of Mendelism and Mutation may yet be illuminated by flashes of electric light as in a polar sky at midnight? But even were I able, there is no time to pursue this thought further.

After all, however, what do we know of electricity? Lord Kelvin declared that in his age he understood it no better than in his youth. The colossal theory we have been considering assumes all the fundamental and hitherto inexplicable laws of electric action. In particular, besides the ether and its wonderful properties, it assumes the law of inverse squares as the mode of all interaction of electrons. Herein of course it is perfectly justified, but the mind cannot lay the importunate query, Why does this interaction vary precisely as the inverse square of the distance? Moreover, since all this action takes place in the uniform universal ether whose regions are distinguishable only by the motions that affect them, the mind is led irresistibly to the conjecture that the problem is ultimately hydrodynamical, that all these electric phenomena must some way be thinkable as movements in an all-pervading medium. Hence then the great significance of the vortex theory developed by Thomson (Kelvin) from the central property of vortex filaments discovered by Helmholtz. Kelvin and his disciples thought to recognize the indissoluble atom in the indissoluble vortex-ring and imagined that an exhaustive doctrine of knots would yield a list of atoms or elements. The new knowledge shows indeed that the atom is not indissoluble, nay, is in some cases actually dissolving, but the vortex-ring or filament is not thereby deprived of its scientific importance. It may yet be that the sub-atom or electron is essentially a vortex in ether, and the theoretic properties of such vortices may be the observed properties of electrons. At this point then the question arises: What is the relation between the equations of electricity and the equations of hydrodynamics? Or between the electromagnetic and the hydrodynamic fields? Or, finally, between the interactions of electric units and of hydrodynamic elements? It seems hard then to exaggerate the moment attaching to such researches as those of the two Bjerknes (father and son) upon fields of force, researches both experimental and mathematical.

They have proved that the relation in question is certainly a close one, that nearly all the elementary actions assumed in electromagnetic theory may be surprisingly simulated by actual experiments on pulses in a liquid medium. True, there presents itself a queer paradox: the hydrodynamic field appears not as the direct but as the inverted image of the electro-magnetic field, attraction and repulsion in the one answering to repulsion and attraction in the other. But in spite of this perversion, the results remain highly interesting and point the way along which research must follow till something more satisfying shall be suggested or discovered.

Meantime it is no more important to see clearly the wide range and immense perspective of the new knowledge than it is to recognize unequivocally its necessary limitations. Even when we suppose the hydrodynamic analogy perfect, even were it possible to state all the facts of the material and ethereal worlds, in a word, of the world of space and sense, in terms of motion rotational or irrotational in a universal ether of whatever properties, even though the vision of the Laplacian Intelligence should thus be actualized on a scale far grander than Laplace himself ever dreamed of, it would still remain true that the real problem of the world was just as far as ever from solution. For let it be understood once for all that this problem is not even to be stated finally in terms of mass and motion, the sole concepts available in the corpuscular or any other physical theory. Mass and motion are not ultimates in human thinking, no physical concepts can be ultimates. The supreme all-comprehending fact of the world is Mind, Soul, Spirit, and the ultimates of all thinking, of all reality, must be psychical. The physical world is an idea, a sensible form, which the mind constructs at every instant by the inherent law of its own activity. It is a splendid, a glorious construct, a real construct, well worthy the everlasting study and admiration of its own creator. Contemplating this amazing creation the Spirit beholds its own image as in a mirror, and it may even explore the depths of its own being by interpreting backward its own image; just as the mathematician may translate the analytic (algebraic) properties of his equation into geometric properties of the corresponding locus and again may interpret the geometric properties of this locus into corresponding algebraic properties of the original equation. But the equation is not the locus, nor ever can be, nor would it cease to be, nor change its properties, if the geometric construction were quite impossible. Speaking then in allegory one may declare that the psychical world is a sublime equation of infinite degree; the physical world is its majestic geometric locus, its construct in terms of time and space, mass and motion. Between the two there subsists or may subsist some one-to-one relation. Let us study the grand image with unreserved admiration and with unflagging zeal. But let us never forget that after all it is only an image, a stupendous parable. Let us never forget the great word of Goethe: *Alles Vergängliche ist nur ein Gleichniss.* Otherwise the brightest achievements of physical and physiological research may prove to be only traps for our unwary feet. Otherwise we shall surely fall into the pit of materialism; we shall mistake the significant for the significate, we shall see in the whole universe only an interplay of corpuscles, and shall talk with Cabanis of the brain secreting thought as the liver secretes bile. Such an issue would be deplorable beyond all words, it would indeed be a bankruptcy of science absolutely hopeless. As secondaries electrons are invaluable; as primaries they are absolutely worthless. The favorite maxim of Sir William Hamilton abides in full validity:

> "On earth is nothing great but man;
> In man is nothing great but mind."

But if even the sublimest flights of physical speculation vouchsafe us no glimpse beyond the veil, how shall we ever lift it? What gaze of reason shall ever penetrate its folds? Who knows indeed that in the nature of the case it can be lifted? For my part I should be content to think it a veil of Isis. Is there not a kind of inspiration in the thought of revelation after revelation, forever and ever, world without end?

> "Higher than your arrows fly,
> Deeper than your plummets fall,
> Is the deepest, the Most High,
> Is the All in All."

Chase without catch would indeed be disheartening, but chase with nothing more to catch would certainly be empty and uninviting. If the chase is to be eternal and yet inspiring, the quarry must be infinite, the supreme truth must be forever approachable but never attainable! In the ancient myth it is said that Egeus concealed from Theseus the secret of his birth, burying the evidence beneath a stone by the seaside. The Father of heaven and earth has perhaps secreted somewhere the proofs of the origin and nature of all things; but upon the shore of what ocean, O man of science, has He rolled the stone that hides them?[3]

WILLIAM BENJAMIN SMITH.

NEW ORLEANS, LOUISIANA.

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[3] Adapted from Maurice Guérin's *Le Centaure.*